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van der Borg, K; Harakeh, MN; van der Werf, SY; van der Woude, A; Bertrand, FE

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A HIGH-RESOLUTION STUDY OF THE GIANT RESONANCE REGION IN ^{28}Si BY INELASTIC α -PARTICLE SCATTERING

K. Van der BORG, M.N. HARAKEH, S.Y. Van der WERF¹ and A. Van der WOUDE

Kernfysisch Versneller Instituut, Groningen, The Netherlands

and

F.E. BERTRAND

*Kernfysisch Versneller Instituut, Groningen, The Netherlands, and
Oak Ridge National Laboratory², Oak Ridge, Tennessee 37830, USA*

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Structure corresponding to various multiplicities is observed in the giant resonance region of ^{28}Si in inelastic α -particle scattering at $E_\alpha = 120$ MeV. In this region ($27 \pm 6\%$) of the isoscalar quadrupole energy weighted sum rule (EWSR) is exhausted. Evidence for a monopole state at 15.9 MeV exhausting 3.2% of the E0 EWSR is presented.

The existence of a giant quadrupole resonance (GQR) has now been well established for nuclei with $A > 40$ [1] but for lighter nuclei there have been conflicting reports of concentrated GQR strength [2–5]. However, recent inelastic α -particle scattering experiments at $E_\alpha = 120$ –173 MeV with a reported energy resolution of 350 to 600 keV on several sd-shell nuclei [6–8] suggest that as the incident α -particle energy is increased above ≈ 100 MeV the broad peak characteristic for the giant resonance region of heavier nuclei also appears for nuclei with $A \geq 16$. On the other hand, an (α, α') experiment [9] on ^{16}O at 104 MeV with much better energy resolution (≈ 150 keV) showed that the single broad peak reported [6] in the poorer resolution experiment on ^{16}O is, in fact, composed of many separate states or clusters of states. Also, in an (α, α') experiment on ^{24}Mg at $E_\alpha = 70$ MeV, considerable E2 strength was located up to 16 MeV excitation, suggesting that the GQR strength in ^{24}Mg is distributed over a broad range of energy [10].

It is interesting then to question whether the broad structure reported [7, 8] in other sd-shell nuclei can also be resolved into separate peaks through the use of higher-resolution (α, α') measurements. Some indications for isoscalar structure have been reported [7,

8], but no analysis of separate peaks was made in those experiments nor in previous (p, p') experiments [5]. Such an analysis not only has the advantage that other than E2 strength can be detected, but it also gives a more detailed picture of the E2 distribution [9].

In this letter we report on the results of a high-resolution inelastic α -particle scattering experiment on ^{28}Si in which we observe considerable structure in the giant resonance region.

The data were obtained with a 120 MeV α -particle beam from the KVI cyclotron. Data were taken simultaneously in two detector telescopes, each consisting of a 2 mm and a 5 mm surface barrier detector. The energy resolution obtained with the telescopes was 90 keV and 150 keV. We used a $700 \mu\text{g}/\text{cm}^2$ enriched ^{28}Si and a $1200 \mu\text{g}/\text{cm}^2$ natural Si target. Most of the data were taken with the natural target which contained very little carbon and oxygen contaminants. The electronic and data handling systems were similar to those described in ref. [9]. Spectra at several angles are shown in fig. 1. At each angle, considerable structure up to $E_x = 23$ MeV is observed which changes as a function of angle, indicating that more than one multipolarity exists in the giant resonance region. The continuum underlying the peaks was assumed to have a shape and magnitude as shown in fig. 1. For the analysis the spectra were divided in energy bins as indicated in fig. 1. These bins were chosen such that

¹ Present address Niels Bohr Institute, Copenhagen, Denmark.

² Operated by Union Carbide Corporation for the U.S. Energy Research and Development Administration.

Fig. 1. Spectra of inelastic α -particle scattering on ^{28}Si . The assumed continuum is indicated for each angle by a solid line. The energy bins which define the different peaks are also shown; the values shown correspond to the centre of the energy bins. For comparison we show in the upper part a spectrum of inelastic proton scattering at 20° .

Fig. 2. The angular distributions for the peaks in ^{28}Si , defined as indicated in fig. 1, for the total sum, for the underlying continuum and for the 2^+ state at 1.78 MeV. The excitation energies (in MeV) are indicated. The curves are the results of DWBA calculations with a collective form factor assuming an L -transfer as indicated.

each peak clearly recognized at several angles was analyzed separately. The angular distributions of the peaks, of the total sum of all the peaks and of the continuum are shown in fig. 2. The experimental data are compared to DWBA calculations made with the computer code DWUCK using a collective-model form factor with real and complex coupling and with optical model parameters obtained from ref. [11]. The angular distribution for most of the peaks is reasonably well described by an $L = 2$ calculation. However, the angular distribution for the 15.9 MeV peak indicates an $L = 0$ transition: the downward trend at very forward angles is quite distinct and can also be observed from a comparison of, for instance, the spectra at 6° and 15° (see fig. 1). More $L = 0$ strength might be present in this energy range as is indicated in fig. 2 and table 1. The peaks at 20.2, 21.5, 22.3 and 22.8 MeV indicate contributions from $L = 3$ transfer. A typical $L = 3$ angular distribution is shown in fig. 2. In table 1 the multipolarity and EWSR depletion is shown for the peaks in the giant resonance region and for the lower 2^+ states. The $T = 0$, 2^+ EWSR for each peak at E_x was determined by normalizing the $\beta R \times E_x$ value to the EWSR strength of the $J^\pi = 2^+$ state at 1.78 MeV as deduced from its adopted half-life [12]. The $L = 0$ EWSR strength was calculated with the prescription of Satchler [13] (option I). In the energy range of $E_x = 15.5\text{--}23.0$ MeV we find a total $T = 0$, 2^+ strength of $(27 \pm 6)\%$ of the EWSR, in good agreement with ref. [7]. The assigned uncertainties are from the uncertainty in the multipolarity assignments only. An additional overall uncertainty of about 20% of the quoted values arises from the continuum subtraction.

A detailed comparison between a (p, p') spectrum [5] at 20° and (α, α') spectra at several angles is shown in fig. 1. The spectra show a remarkable overlap indicating that most of the fine-structure observed in the (p, p') reaction arises from excitation of isoscalar states.

If for the calculation of the (p, p') cross sections of the GDR in ^{28}Si the Jensen–Steinwedel model for E1 excitation is used [14], it turns out that the measured (p, p') cross sections are consistent with GDR excitation only and none or a very small GQR excitation. However, by using the Goldhaber–Teller (G–T) model, an additional GQR excitation exhausting $(15 \pm 5)\%$ of the E2 EWSR is needed to explain the (p, p') data. Our results clearly show that the G–T model

Table 1
Deformation lengths and percentages of EWSR for isoscalar excitations observed in $^{28}\text{Si}(\alpha, \alpha')$

E_x^a (MeV)	J^b	βR^c	S^d (% EWSR)	E_x^a (MeV)	J^b	βR^c	S^d (% EWSR)
1.78	2	1.37	13.0	17.3	2	0.20	2.6
7.42	2	0.32	4.0		(0)	0.24	6.3
7.93	2	0.19	1.6	17.9	2	0.15	1.6
9.52	2	0.14	0.7		(0)	0.18	3.6
10.60	2	0.12	0.6	18.1	2	0.17	2.0
11.65	2	0.14	0.9	18.8	2	0.26	5.1
13.75	(2)	0.16	1.4	19.3	2	0.18	3.3
14.82	(2)	0.21	2.6	19.9	2	0.21	3.3
				20.2	(2, 3)	0.15	1.7
15.9	(0)	0.18	3.2	20.7	2	0.21	3.6
16.1	(2, 3)	0.16	1.6	21.5	(2, 3)	0.20	3.3
16.8	(2)	0.19	2.5	22.3	(2, 3, 4)	0.09	0.7
	(0)	0.21	4.9	22.8	(2)	0.14	1.7
17.0	(2)	0.11	0.8	15.9–22.8	(2)	0.67	31.8

^a As obtained from this experiment.

^b Assumed J -value.

^c Obtained from a collective model analysis assuming $J^\pi = 2^+$ or 0^+ . The quoted values have a 20% uncertainty.

^d Obtained from a collective model analysis except for the $E_x = 1.78$ MeV state for which the known $B(E2)$ value was used (see text).

has to be used for calculating the GDR cross section in (p, p') scattering.

In summary, we find that the giant resonance region in ^{28}Si is highly structured. Most of the identifiable peaks have E2 multipolarity but definite evidence for other multipolarities was found. Of special importance is the observation that a peak at 15.9 MeV is most likely produced by $L = 0$ transfer. It has to be a $2\hbar\omega$ (1p–1h) transition and as such might be considered part of the giant monopole resonance. The trend toward spreading of the GQR strength in light nuclei is similar to that observed for the GDR in these nuclei [15]. The amount of the isoscalar quadrupole EWSR strength exhausted in the giant resonance region of ^{28}Si between 15.5 and 23 MeV is $(27 \pm 6)\%$.

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